METHOD AND APPARATUS FOR ELECTROSURGICAL ABLATION

RELATED APPLICATIONS

This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Application Serial No. 60/458,489, entitled "Electrode for Electrophysiology Catheter Having an Eccentric Surface", filed on March 28, 2003, U.S. Provisional Application Serial No. 60/458,490, entitled "Electrophysiology Catheter Allowing Adjustment Between Electrode and Tissue Gap", filed on March 28, 2003, U.S. Provisional Application Serial No. 60/458,491, entitled "Shape Shifting Electrode Geometry for Electrophysiology Catheters", filed on March 28, 2003, U.S. Provisional Application Serial No. 60/458,643, entitled "Method and Apparatus for Selecting Temperature/Power Set Points in Electrophysiology Procedures", filed on March 28, 2003, and U.S. Provisional Application Serial No. 60/458,856, entitled "Catheter Tip/Electrode Junction Design for Electrophysiology Catheters" filed on March 28, 2003, all five of which are each incorporated herein by reference in their entireties.

BACKGROUND OF INVENTION

1. Field of Invention

The invention relates to medical devices and methods for performing ablation procedures. More particularly, the invention relates to methods and apparatus for adjusting distances between (1) a tissue surface and (2) an ablation electrode and/or a catheter shaft.

2. Discussion of Related Art

The human heart is a very complex organ, which relies on both muscle contraction and electrical impulses to function properly. The electrical impulses travel through the heart walls, first through the atria and then the ventricles, causing the corresponding muscle tissue in the atria and ventricles to contract. Thus, the atria contract first, followed by the ventricles. This order is essential for proper functioning of the heart.

Over time, the electrical impulses traveling through the heart can begin to travel in improper directions, thereby causing the heart chambers to contract at improper times. Such a condition is generally termed a cardiac arrhythmia, and can take many different forms. When the chambers contract at improper times, the amount of blood pumped by the heart decreases, which can result in premature death of the person.

Techniques have been developed which are used to locate cardiac regions responsible for the cardiac arrhythmia, and also to disable the short-circuit function of these areas. According to these techniques, electrical energy is applied to a portion of the heart tissue to ablate that tissue and produce scars which interrupt the reentrant conduction pathways or terminate the focal initiation. The regions to be ablated are usually first determined by endocardial mapping techniques. Mapping typically involves percutaneously introducing a catheter having one or more electrodes into the patient, passing the catheter through a blood vessel (e.g. the femoral vein or artery) and into an endocardial site (e.g., the atrium or ventricle of the heart), and deliberately inducing an arrhythmia so that a continuous, simultaneous recording can be made with a multichannel recorder at each of several different endocardial positions. When an arrythormogenic focus or inappropriate circuit is located, as indicated in the electrocardiogram recording, it is marked by various imaging or localization means so that cardiac arrhythmias emanating from that region can be blocked by ablating tissue. An ablation catheter with one or more electrodes can then transmit electrical energy to the tissue adjacent the electrode to create a lesion in the tissue. One or more suitably positioned lesions will typically create a region of necrotic tissue which serves to disable the propagation of the errant impulse caused by the arrythromogenic focus. Ablation is carried out by applying energy to the catheter electrodes. The ablation energy can be, for example, RF, DC, ultrasound, microwave, or laser radiation.

Atrial fibrillation together with atrial flutter are the most common sustained arrhythmias found in clinical practice.

Another source of arrhythmias may be from reentrant circuits in the myocardium itself. Such circuits may not necessarily be associated with vessel ostia, but may be interrupted by means of ablating tissue either within the circuit or

circumscribing the region of the circuit. It should be noted that a complete 'fence' around a circuit or tissue region is not always required in order to block the propagation of the arrhythmia; in many cases simply increasing the propagation path length for a signal may be sufficient. Conventional means for establishing such lesion 'fences' include a multiplicity of point-by-point lesions, dragging a single electrode across tissue while delivering energy, or creating an enormous lesion intended to inactivate a substantive volume of myocardial tissue.

In creating lesions, care is taken to limit blood coagulation and tissue charring and desiccation. These undesirable effects can occur if temperatures in the tissue or blood rise to 100°C. In addition to effects on the blood and tissue, temperatures of 100°C or more at the electrode-tissue interface can foul an electrode due to tissue charring. Various strategies are employed to maintain temperatures below 100°C. For example, electrode cooling (active and/or passive) is employed in an attempt to cool the tissue at the tissue surface where temperatures can often be the highest, thereby allowing a more even temperature distribution in the tissue. Other strategies include limiting the power applied to the electrode based on pre-determined estimates of appropriate power levels, and reducing the power applied to the electrode in response to feedback signals from the electrode or other sensors. Reduced power application, however, is balanced with the desirability of raising the temperature of an adequate volume of tissue above its viability temperature and the benefits of reducing total procedure time.

There exists a need to improve the delivery of energy to tissue to form lesions without exceeding temperatures that result in charring, desiccation or blood coagulation.

SUMMARY OF INVENTION

Embodiments of the present invention encompass apparatus and method for creating lesions in heart tissue (ablating) to create a region of necrotic tissue which serves to disable the propagation of errant electrical impulses caused by an arrhythmia. Embodiments of the present invention also encompass apparatus and

methods for adjusting distances between (1) a tissue surface and (2) an ablation electrode and/or a catheter shaft.

According to one embodiment, a catheter for ablating tissue comprises:

a shaft for positioning an ablation ring electrode in contact with or near a tissue surface, and an ablation ring electrode disposed on the shaft. A distance from the shaft near the ablation ring electrode to the tissue surface is adjustable.

According to another embodiment, a method of adjusting a distance between a shaft and a tissue surface comprises positioning a catheter shaft at a first distance from a tissue surface, the catheter shaft surface being near an ablation ring electrode that is mounted on the shaft, and moving the shaft to a second, different distance from the tissue surface.

According to a further embodiment, a catheter for ablating tissue comprises a shaft for positioning an ablation electrode in contact with a tissue surface, the shaft having a longitudinal axis, and an ablation electrode rotatably disposed on the shaft and constructed and arranged to change a distance between the shaft and the tissue surface when rotated around the shaft longitudinal axis.

According to another embodiment, a catheter for ablating tissue comprises a shaft having a longitudinal axis, and an ablation electrode disposed on the shaft and having a continuous outer surface. The electrode outer surface circumscribes the shaft along a length of the shaft and is eccentric in a radial cross-section.

According to a further embodiment, a catheter for ablating tissue comprises a shaft for positioning an ablation electrode in contact with a tissue surface, the shaft having an outer surface that is eccentric in a cross-section, and an ablation electrode disposed on the shaft. In a first shaft orientation, the shaft outer surface is positioned a first distance from the tissue surface in the vicinity of the ablation electrode, and in a second, rotated shaft orientation, the shaft outer surface is positioned a second distance from the tissue surface in the vicinity of the ablation electrode, the second distance being different than the first distance.

According to another embodiment, a catheter for ablating tissue comprises a shaft for positioning an ablation electrode at a distance from a tissue surface and an ablation electrode disposed on the shaft and having an outer surface. The ablation

electrode is moveable along the shaft in a longitudinal direction and the shaft is configured such that movement of the ablation electrode along the shaft in the longitudinal direction changes the distance between the electrode outer surface and the tissue surface.

According to a further embodiment, a catheter for ablating tissue comprises a shaft for positioning an ablation electrode in contact with a tissue surface, and an ablation electrode disposed on the shaft and having an outer surface. The ablation electrode is moveable along the shaft in a longitudinal direction and the shaft is configured such that movement of the ablation electrode along the shaft in the longitudinal direction positions the electrode surface at a distance from the tissue surface.

According to another embodiment, a catheter for ablating tissue comprises a shaft for positioning an ablation electrode at a distance from a tissue surface, and an ablation electrode rotatably disposed on the shaft and constructed and arranged to change a distance between an outer surface of the ablation electrode and the tissue surface when rotated relative to the shaft longitudinal axis.

According to a further embodiment, a method of changing a distance from an outer surface of a catheter shaft to a tissue surface comprises placing an ablation electrode into contact with a tissue surface using a catheter shaft such that an outer surface of the catheter shaft is disposed a distance from the tissue surface in the vicinity of the ablation electrode. The method further comprises rotating the ablation electrode to change the distance from the outer surface of the catheter shaft to the tissue surface.

According to another embodiment, a method of changing a distance from an ablation electrode to a tissue surface comprises disposing an ablation electrode at a first distance from a tissue surface using a catheter shaft having a longitudinal direction, and disposing the ablation electrode at a second distance, different than the first distance, from the tissue surface by moving the ablation electrode along the catheter shaft in the longitudinal direction.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings are not intended to be drawn to scale. In the drawings, like components that are illustrated in various figures are given like numerals. For purposes of clarity, not every component may be labeled in every drawing. In the drawings:

Fig. 1 is illustrates a catheter system in accordance with embodiments of the present invention;

Fig. 2 illustrates a side view of a catheter shaft with ring electrodes as known in the art;

Fig. 3 illustrates a side view of a circular ablation electrode disposed eccentrically on a circular catheter shaft in a first orientation according to one embodiment of the invention;

Fig. 4 illustrates a side view of the ablation electrode illustrated in Fig. 3 in a second orientation;

Fig. 5 is a cross-sectional view taken along line V-V of the embodiment illustrated in Fig. 3;

Fig. 6 is a cross-sectional view of an eccentrically-shaped ablation electrode disposed concentrically on a circular catheter shaft according to an embodiment of the invention;

Fig. 7 is a cross-sectional view of an eccentrically-shaped ablation electrode disposed eccentrically on a circular catheter shaft according to an embodiment of the invention;

Fig. 8 is a cross-sectional view of a circular ablation electrode disposed concentrically on a eccentrically-shaped catheter shaft according to an embodiment of the invention;

Fig. 9 is a cross-sectional view of an eccentric ablation electrode disposed on a circular catheter shaft according to an embodiment of the invention;

Fig 10 is a longitudinal cross-sectional view of an ablation electrode eccentrically disposed on a catheter shaft;

Fig. 11 is a side view of a moveable ablation electrode disposed on a catheter shaft according to a further embodiment of the invention;

Fig. 12 is a side view of an eccentrically-shaped ablation electrode disposed on a circular catheter shaft according to a further embodiment of the invention;

Fig. 13 is a cross-sectional view taken along line XIII-XIII of the embodiment illustrated in Fig. 12;

Fig. 14 is a side view of an circular ablation electrode disposed on an eccentrically-shaped catheter shaft according to another embodiment of the invention;

Fig. 15 is a cross-sectional view taken along line XV-XV of the embodiment illustrated in Fig. 14;

Fig. 16 is a side view of a moveable ablation electrode disposed eccentrically on a catheter shaft;

Fig. 17 shows a side view of a catheter with a moveable sheath according to one embodiment of the invention;

Fig. 18 shows a perspective view of an ablation electrode with an eccentric surface; and

Fig. 19 shows a perspective view of an ablation electrode with an asymmetric cross-section mounted to a catheter shaft.

DETAILED DESCRIPTION

This invention is not limited in its application to the details of construction and the arrangement of components and acts set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having," "containing", "involving", and variations thereof herein, is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

During ablation procedures, one objective is to raise tissue temperatures above the tissue's viability temperature without allowing the temperatures to exceed approximately 100°C. As described above, excessive temperatures can cause tissue charring, tissue desiccation, and/or blood coagulation. Blood flow at and near the tissue surface can remove heat from the tissue and affect the temperature distribution within the tissue. As illustrated in Fig. 2, typically, ablation electrodes 15 are mounted on a catheter shaft 11 such that outer surfaces of the ablation electrodes are

flush with the outer surface of the catheter shaft. During ablation procedures with such catheters, the electrodes, and therefore the catheter shaft, are positioned in contact with a tissue surface 25. The shaft and electrodes can inhibit blood flow across the tissue surface in and around the contact area.

Applicants have recognized that adjusting the distance between a catheter shaft and a tissue surface can be advantageous in certain blood flow conditions. For example, in some high blood flow conditions, it may be desirable to move the catheter shaft further away from the tissue surface to allow increased blood flow across the tissue surface. In other blood flow conditions, having the catheter shaft closer to or in contact with the tissues surface may be desirable.

Applicants have also recognized that in many instances positioning an ablation electrode at a distance from a tissue surface can improve lesion size and bring about a more even distribution of temperature within the tissue. In certain embodiments of the invention, an outer surface of an ablation electrode may be disposed on catheter shaft at a distance from a tissue surface, and in further embodiments, the distance may be adjustable.

<u>System Overview</u>

Reference is now made to Fig. 1, which figure illustrates an overview of an ablation catheter system in accordance with embodiments of the present invention. The system includes a catheter 10 having a shaft 12, a control handle 14, and a connector portion 16. A control module 8 is connected to connector portion 16 via cable 6. Ablation energy supply 4 may be connected to control module 8 via cable 3. Control module 8 is used to control ablation energy provided by ablation energy supply 4 to catheter 10. Although illustrated as separate devices, ablation energy supply 4 and control module 8 could be incorporated into a single device. Control handle 14 may include a rotatable thumb wheel 17 which can be used by a user to deflect the distal end of the catheter, rotate electrodes, or move electrodes longitudinally along the catheter shaft. Thumb wheel 17 (or any other suitable actuating device) may be connected to one or more pull wires which extend through shaft 12 and are connected to the distal end or to electrodes 20. Additional actuating

devices (not shown) may be provided on control handle 14 for controlling various mechanisms associated with shaft 12 or electrodes 20.

In this description, various aspects and features of embodiments of the present invention will be described. The various features of the embodiments of the invention are discussed separately for clarity. One skilled in the art will appreciate that the features may be selectively combined in a device depending upon the particular application. Furthermore, any of the various features may be incorporated in a catheter and associated methods of use for ablation procedures.

Catheter Overview

Catheter 10 includes shaft 12 and a distal tip electrode 18 and/or one or more ring electrodes 20. As described below in more detail, ring electrodes 20 may be arranged on shaft 12 such that their outer surfaces have cross-sectional widths that are larger or smaller than cross-sectional widths of shaft 12. In some embodiments, ring electrodes 20 may be non-circular in shape, may be adjustable in size or shape, may be moveable along shaft 12, or may be disposed eccentrically on shaft 12. In other embodiments, the outer surfaces of ring electrodes 20 may be flush with the shaft surface.

Adjustment of Distance between Shaft and Tissue Surface

Referring now to Figs. 3-5, an ablation electrode 21 is disposed on shaft 12 such that electrode 21 and shaft 12 are eccentric. As can be seen in Fig. 5, a center longitudinal axis 24 of shaft 12 is not concentric with a center longitudinal axis 26 of ablation electrode 21. Electrode 21 has a larger diameter than shaft 12 and when outer surface 27 of electrode 21 is placed in contact with a tissue surface 25, shaft 12 is spaced a distance *D* from tissue surface 25. When electrode 21 is orientated relative to a tissue surface 25 in a first orientation as shown in Fig. 3, shaft 12 is closer to tissue surface 25 than when electrode 21 is rotated into a second, different orientation as shown in Fig. 4.

Electrode 21 may be rotatable relative to shaft 12 in some embodiments. For example, an inner surface 28 of electrode 21 may be configured to slide over an outer

surface 30 of shaft 12. A stop (not shown) may be provided to limit the rotation range of electrode 21.

In other embodiments, shaft 12 may be attached to electrode 21 such that rotation of shaft 12 rotates electrode 21. In one such embodiment, to rotate electrode 21, all of shaft 12 may be rotated. In other embodiments where shaft 12 is attached to electrode 21, longitudinal portions of the shaft may be rotatable, thereby permitting rotation of the electrode without rotating the entire shaft. For purposes herein, the phrase "rotating X around a longitudinal axis of Y" can include rotating X relative to Y and rotating X together with Y.

For purposes herein, references to a distance from an electrode or a shaft to a tissue surface means the closest distance between an outer surface of the electrode or the shaft the tissue surface. For purposes herein, an element having a particularly shaped cross-section is not intended to restrict the element to having such a particularly shaped cross-section along the entire element. A portion or portions of the element may have the described cross-section. For purposes herein, rotation of an element such as a catheter shaft or an electrode may refer to the rotation of a portion of the element. For example, rotation of a shaft can mean rotation of a longitudinal portion of the shaft.

In the embodiment illustrated in Figs. 3-5, there is a continuous range of distances that may be selected. A minimum distance *D* from shaft 12 to tissue surface 25 is achieved at the orientation shown in Fig. 5. A maximum distance *D* would be achieved by rotating the electrode 180° from the orientation shown in Fig. 5. In one embodiment, the maximum distance is approximately 0.031 inches. By controlling the orientation of electrode 21, any distance *D* that falls between the maximum and minimum distances may be selected.

In some embodiments, outer surface 27 of electrode 21 is constructed of a single piece of material. Although not required in all embodiments, electrode outer surface 27 may be stiff so that the general shape of outer surface 27 does not change during normal use. The stiffness may be achieved through use of particular materials or construction. In various embodiments, outer surface 27 of electrode 21 is a continuous surface, unlike mesh electrodes that have gaps between structural surfaces.

In another illustrative embodiment, as shown in Fig. 6, electrode 21 and shaft 12 are concentric, but the electrode 21 is eccentrically shaped. Similar to the embodiment illustrated in Figs. 3-5, rotation of electrode 21 results in a change in the distance *D* between shaft 12 and tissue surface 25. In this embodiment, however, the maximum and minimum distances D are separated by rotations of 90° instead of 180°. The thickness of electrode 21 has a different symmetry than that of the embodiment illustrated in Figs. 3-5. In the embodiment of Figs. 3-5, outer surface 27 of electrode 21 is circular, but because electrode inner surface 28 and electrode outer surface 28 are eccentric, the thickness is bilaterally symmetric about only one axis in the plane of the drawing. In the embodiment of Fig. 6, the thickness of electrode 21 may vary continuously around the electrode, but the electrode has bilateral symmetry about more than one axis in the plane of the drawing. The thickness of electrode 21 need not be symmetric, nor must the thickness vary continuously around the entire electrode, and in some embodiments, certain portions or the entirety of the electrode may have a constant thickness.

Fig. 7 shows an illustrative embodiment of an eccentrically-shaped ablation electrode 21 eccentrically disposed on shaft 12. In this embodiment, shaft 12 is positioned eccentrically toward a longer radius side of ablation electrode 21. In the orientation illustrated in Fig. 7, shaft 12 is closer to tissue surface 25 than it is when electrode 21 is rotated 180° from the illustrated orientation. Shaft 12 is moved a further distance from tissue surface 25 by both the eccentric shape of electrode 21 and the eccentric mounting of electrode 21. In other embodiments, shaft 12 may be positioned toward a shorter radius side of ablation electrode 21 or somewhere in between a shorter radius side and a longer radius side.

Fig. 8 illustrates an alternative embodiment in which electrode 21 is circular in cross-section and shaft 12 is eccentrically shaped. With such an arrangement, rotation of shaft 12, regardless of whether fixed to electrode 21, changes the distance from outer surface 23 of shaft 12 to tissue surface 25. Shaft 12 may be configured to extend to outer surface 27 of electrode 21 along portions of the electrode perimeter such that in certain orientations, shaft 12 is in contact with tissue surface 25. In other embodiments, portions of shaft 12 may be configured to extend beyond outer surface

27 of electrode 21 along portions of the electrode perimeter such that in some orientations, electrode 21 is spaced from tissue surface 25, while in other orientations, shaft 12 is spaced from tissue surface 25.

Referring now to Fig. 9, in another embodiment, electrode 21 may have a flat surface 34 that increases a contact area between electrode 21 and tissue surface 25 when electrode 21 is placed in a certain orientation. As illustrated in Fig. 9, flat surface 34 may be positioned on electrode outer surface 27 such that shaft 12 is at a maximum distance from tissue surface 25 when flat surface 34 is in contact with tissue surface 25. This arrangement may facilitate positioning electrode 21 at a known, pre-determined distance from tissue surface 25. In other embodiments, more than one flat surface may be provided and in still further embodiments the entire electrode outer surface 27 may be formed with flat surfaces. Various flat surfaces may space shaft 12 at different distances from tissue surface 25. In such an embodiment, a measurement of the rotation angle of the electrode can indicate the distance from shaft 12 to tissue surface 25.

Referring now to Fig. 10, one embodiment of an attachment of electrode 21 to shaft 12 and an electrical connection of electrode 21 is illustrated. Lumen 42 extends longitudinally through shaft 12. An electrical lead 48 for providing electrical energy to electrode 21 runs through lumen 42 and passes through a passage 44 in a shaft wall 46 near electrode 21. Electrical lead 48 is soldered, welded, or otherwise electrically connected to electrode 21. If electrode 21 is configured to rotate with shaft 12, electrode 21 may be fixed to shaft 12 with a suitable adhesive or other suitable fixing means. As is known to one skilled in the art, other electrode attachment arrangements are possible.

In embodiments of the present invention that include an electrode that is rotatable relative to shaft 12, an electrical connection between electrical lead and electrode 21 may be accomplished with a brush (not shown) or a biased protrusion (not shown) that remains in contact with an inner surface of a rotating electrode 21.

Adjustment of Distance between Electrode and Tissue Surface

Referring now to Fig. 11, a catheter arrangement for adjusting a distance *G* between electrode outer surface 27 and tissue surface 25 is illustrated. In this embodiment, electrode 21 is moveable along shaft 12 in the longitudinal direction. Shaft 12 is configured to be spaced from tissue surface 25 along a length *L* of shaft 12. Longitudinal movement of electrode 21 from a first position 38 outside length *L* to within length *L* brings electrode 21 out of contact with tissue surface 25. As electrode 21 continues to move along length *L* toward a second position 39, the distance from electrode outer surface 27 to tissue surface 25 increases. Further movement beyond second position 39 in the same direction decreases the distance in the illustrated embodiment. Different slopes of shaft 12 may be used and limits on longitudinal movement may be provided by the mechanism used to move electrode 21 or by barriers, stops or other impediments to movement positioned on shaft 12.

Shaft 12 may be urged into a bent position with pull wires or other mechanisms controllable with control handle 14. In some embodiments, shaft 12 may be configured to be bent when no forces are acting on it. A certain amount of the bending of shaft 12 may be resilient in that while shaft 12 is flexible and may be forced into an unbent state, the shaft at least partially returns to a bent state upon release of the force.

Other arrangements may be used to adjust distances between ablation electrodes and tissue surfaces. One such arrangement is shown by way of example in Figs. 12 and 13. In this embodiment, electrode 21 is constructed such that when shaft 12 is in contact with a tissue surface, electrode 21 is spaced a distance from the tissue surface. Electrode 21, which has an eccentrically-shaped cross-section, is disposed on shaft 12, which has a circular cross-section. By rotating electrode 21, the distance between electrode 21 and the tissue surface can be altered. Electrode 21 may be rotated relative to shaft 12, or in other embodiments, electrode 21 may be rotated with shaft 12.

Figs. 14 and 15 show an alternative embodiment in which electrode 21 is configured to be spaced from tissue surface 25 and the distance between the two is adjustable. In this embodiment, shaft 12 has a cross-section that is eccentrically

shaped. Rotation of shaft 12 adjusts the distance from electrode outer surface 27 to tissue surface 25. In the embodiment shown in Figs. 14 and 15, electrode 21 is disposed concentrically with shaft 12. In either of the embodiments illustrated in Figs. 13 and 15, or other embodiments, electrode 21 and shaft 12 may be disposed eccentrically.

An embodiment incorporating both an eccentrically-disposed electrode and a shaft which is spaced from a tissue surface is illustrated in Fig. 16. In this embodiment, a distance between electrode 21 and tissue surface 25 may be altered by moving electrode 21 longitudinally along shaft 12. Additionally, the distance may be changed by rotating electrode 21 when electrode 21 is positioned at a suitable longitudinal location. In some instances, it may be more desirable to move electrode 21 longitudinally than to rotate electrode 21. In other instances, the opposite may be true. In some instances, it may be desirable to have the option of having electrode 21 in contact or out of contact with tissue surface while shaft 12 is not in contact with tissue surface 12. In the embodiment illustrated in Fig. 16, at longitudinal position 41, electrode 21 may be rotated to contact tissue surface 25, or, as shown, electrode 21 may be out of contact with tissue surface 25 while shaft 12 remains spaced from tissue surface 25.

A sheath may be used to space an electrode from a tissue surface in an illustrative embodiment of the invention, as shown in Fig. 17. A sheath 50 encompasses shaft 12 and is moveable in the longitudinal direction of shaft 12. As sheath 50 gets close to ring electrode 21, ring electrode 21 is lifted away from tissue surface 25. In one embodiment, sheath 50 may be eccentrically shaped so that rotating the sheath can adjust the distance that ring electrode 21 is spaced from tissue surface 25.

An electrode 21 that has an outer surface that is rounded in the longitudinal direction is illustrated in Fig. 18. In the embodiment shown, electrode 21 is rounded on one side of the electrode, but different areas of electrode 21 could be rounded in the longitudinal direction.

Fig. 19 shows an embodiment of an electrode 21 that is attached to shaft 12 such that the mass of the electrode is primarily on one side of shaft 12. Because most

of the mass and surface area of ablation electrode 21 is on one side of the catheter, the electric field resulting from the transmission of energy by ablation electrode 21 may be different than an electric field resulting from an ablation electrode that evenly encircles a catheter shaft. The embodiment of Fig. 19 provides some directionality to the electric field such that heating of the blood may be less than with similarly sized and powered electrodes that circumscribe shaft 12.

A loop portion 52 of electrode 21 extends around shaft 12 to hold electrode 21 on shaft 12. In other embodiments, a electrically non-conductive loop or clip may be used to hold electrode 21 on shaft 12.

Having thus described several aspects of at least one embodiment of this invention, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description and drawings are by way of example only.

What is claimed is: